Journal of Veterinary Behavior 10 (2015) 12–16

Contents lists available at ScienceDirect

Journal of Veterinary Behavior

journal homepage: www.journalvetbehavior.com

Research

Influence of changes in luminous emittance before bedtime on sleep in companion dogs

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ARTICLE INFO

Article history:
Received 30 June 2014
Received in revised form
24 July 2014
Accepted 2 September 2014
Available online 16 September 2014

Keywords:
circadian rhythm
dog
behavioral response
luminous intensity before bedtime
sleep quality

ABSTRACT

Sleep is important for animals to stay healthy and recover from exhaustion. This study evaluated the effect of changes in luminous emittance before "lights-out" on sleeping behavior in dogs. Six healthy dogs (aged 15-51 months; 3 female and 3 male) were exposed individually to each of the 3 different luminous emittances: 600 lux as the control condition, 50 lux as the poorly lit condition, and 1600 lux as the brightly lit condition before "lights-out" (from 4 PM to 9 PM) for 2 days in succession, over a total 6-day period. For each exposure, we observed the dogs' behaviors from 4 PM to 7 AM the following day. The order of the 3 luminous intensities was random. Eye condition (open or closed), head position (contact or no contact with the floor or side of cage), posture (6 categories), and behavior (8 categories) were recorded every 15 seconds. Comparisons between the conditions on the number of events spent in each posture or behavior were assessed using a repeated-measures analysis of variance, with post hoc comparisons, and a $P < 0.05$ was used to assess significance. A paired t test was used to compare eye or head positions under each condition. During the period 4 PM-5:30 PM, there was no difference among the 3 conditions in terms of the number of events each posture or each behavior was shown. From 5 AM to 7 AM, after exposure to poorly lit conditions, the number of events involving lateral recumbency was significantly greater than that in the control (Tukey, $P < 0.05$). From 5 AM to 7 AM, after exposure to poorly lit or brightly lit conditions, the number of events involving eyes closed was significantly greater than that spent aroused (t test, $P < 0.05$), but otherwise there were no significant differences compared with the controls. These results suggest that changes in luminous intensity before night time might influence sleep quality in dogs.

Introduction

In domestic species, many behaviors differ from those seen in the wild because the animals are controlled by humans (Piccione et al., 2014). In particular, dogs living as pets with humans have to adjust to their owner's life rhythms and habitat. The activity of companion dogs is dependent on their housing environment, and it is influenced by human presence and care (Piccione et al., 2013). Among physiological behaviors, the pattern of sleeping and waking in dogs is also influenced by their living environment (Adams and Johnson, 1993). Sleep may not always provide normal rest for pet dogs. The human sleep cycle commonly consists of rapid eye movement (REM) and non–rapid eye movement (NREM) sleep, alternating on a cycle of 90 minutes (Speigel, 1981). When humans are falling asleep, NREM sleep appears first. After about 1 or 2 hours, the cycle moves to REM sleep; NREM sleep and REM sleep thus appear in turns. Several authors studied the sleep cycle in dogs and showed that REM is likely to occupy about 20% of the total sleep time in dogs, and the mean REM cycle lasts 30 minutes (e.g., Latash et al., 1977). In animal physiology and behavior, melatonin plays a physiological role in the timing of seasonal rhythms (Brown, 1994). Melatonin levels depend on illumination; strong illumination before bedtime has a strong negative influence on human sleep quality. Studies on humans showed that bright-light treatment has acute phase-shifting effects that can reset the human circadian rhythm (Czeisler et al., 1989). Honma and Honma (1988) found that bright-light around bedtime causes phase delay in the human sleep-wakefulness rhythm, and bright light around the time of

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http://dx.doi.org/10.1016/j.jveb.2014.09.001
1558-7878/

rising causes phase advancement of the rhythm. In human circadian rhythms, it has also been suggested that the phase-shifting effect of light has a strongly nonlinear relationship with illuminance levels (Boivin et al., 1994). Studies of the effects of optimum illuminance and color temperature in bedrooms suggest that low–color temperature light creates a smooth lowering of central nervous system activity and that low–color temperature illumination can be used effectively in bedrooms or other such environments where it is desirable to facilitate a reduction in physiological activity (Noguchi and Sakaguchi, 1999). Despite these findings, there is no evidence of bright-light treatment effect on the sleeping pattern in dogs, and there is little information available on the relationship between the light levels at bedtime and dog circadian rhythms or behavior at night. The purpose of this study was to investigate the influence of different luminous emittances before lights-out on sleeping behavior in dogs.

Materials and methods

Animals

Six healthy dogs, 2 German Shepherds, 1 Labrador Retriever, 1 Golden Retriever, and 2 crossbreds (3 females and 3 males) participated in this study. The dogs varied in age (from 15 to 51 months) and in weight (from 13.2 to 36.4 kg). All dogs were allowed contact with the outside environment and with humans at any time. They were able to sleep alone without distress; hence, they were caged singly at night.

Experimental schedule

A room at Nihon University was used for the experiment. During the experimental period, each dog was accommodated in a wire cage to which was attached a water bottle. Four CCD cameras which set the four corners of the cage, were used to record dog behavior during the night. The size of the cage (large: 68 × 106 × 75 cm; medium: 60 × 90 × 71 cm; small: 55 × 74 × 65 cm) was selected such that each dog could comfortably achieve various postures, such as sternal recumbency, lateral recumbency, sitting, and standing.

First, all dogs were videotaped individually either 1 or 2 days before the start of the experiment when sleeping in their usual kennels; the lights-out time was 8 PM. After this, each dog was habituated to the experimental room under control lighting conditions (luminous emittance, 600 lux) for 6 contiguous days before the experiment because the experimental room differed from their usual kennels. During these observation days, rest time was defined as occurring when the dog was in sternal, lateral, or dorsal recumbency or curling up.

Because the average luminous emittance of the dogs' usual housing was 600 lux, this luminous emittance was defined as the control lighting condition. We used the following 3 lighting conditions before bedtime: 600 lux (FLR40S W/M-36; National, Osaka, Japan) as the control lighting condition, 1600 lux (FLR40SD/M-B, Hitachi, Tokyo, Japan; FLR40S W/M-36, National, Osaka, Japan) as the brightly lit condition, and 50 lux as the poorly lit condition. Luminous emittance in the room was measured with an illuminance meter (AHLT-102SD, Custom, Tokyo, Japan) every day. Overhead lighting (ceiling height 240 cm) was used for both environments (i.e., their usual kennels and the experimental room).

Each dog was exposed to the control conditions for 2 evenings after habituation. Both poorly lit and brightly lit conditions were randomly allocated to each dog for 2 evenings after the control-lit conditions.

Table 1
Condensed observational categories

Observational category	Description
Eye position	
Open	Dog keeps its eyes open
Closed	Dog closes its eyes
Head position	
Contact	Dog's head contacts floor or side of cage
Noncontact	Dog's head is not in contact with floor or side of cage
Posture	
Sternal recumbency	Dog lies down and its belly contacts floor
Lateral recumbency	Side of dog's body contacts floor during rest or sleep
Dorsal recumbency	Dog's back contacts floor during rest or sleep
Curling up	Side of dog's body contacts cage; dog curls up into a ball during rest or sleep
Sitting	Dog sits on floor of cage during rest or sleep
Standing	Dog stands on all 4 limbs when at rest
Behavior	
Vocalizing	Dog barks or growls
Yawning	Dog opens mouth widely and exhales
Panting	Dog pants with open mouth
Grooming	Dog grooms its body with its tongue
Scratching	Dog scratches its body
Stretching	Dog stretches its forelegs or hind legs
Drinking	Dog drinks water
Excretion	Dog urinates or defecates

Before the start of the experiment, each dog was given rest time in its own usual kennel from 3:30 PM. After about 20 minutes, the experimenter (a female in her 20s) took the dog outside for toileting. At 4 PM, the experimenter entered the experimentally lit room with the dog. The experimenter then removed the dog's collar, placed the dog in the cage, and sat on a chair with her back to the dog. At 5:30 PM, the experimenter took the dog for a walk for 30 minutes. After the exercise, the dog was given a short rest and then fed. Each dog spent 15 hours (4 PM-7 AM) in the experimental room each day for 6 contiguous days before the experiment began. The room was lit from 4 PM until 9 PM, at which time the experimenter left the room. The experimenter returned at 7 AM, turned the lights on, and took the dog for a walk.

Behavioral category

Four CCD cameras were used to record the dog's behavior during the experimental period. Eye position (open or closed), head position (contact or no contact with the floor), 6 categories of posture, and 8 categories of behavior were recorded every 15 seconds (Table 1) from 4 PM to 7 AM the following day. These recorded data were divided into 4 blocks (4 PM-5:30 PM; 9 PM-11 PM; 1 AM-3 AM; and 5 AM-7 AM) for data collection purposes.

Statistical analysis

The initial analysis used a repeated-measures analysis of variance to assess the effect of subject, lighting conditions, and repetition on the number of periods spent in each posture or behavior. Post hoc Tukey tests were used for pairwise comparison of the means of the number of periods when significant effects were found. A paired t test was used for the comparison of eye or head positions under each lighting condition.

Table 2
Total number of periods (arbitrary units) of eye conditions and head positions during/after exposure to the 3 lighitng conditions

Condition/position	During exposure						After exposure					
	4 PM-5:30 PM			9 PM-11 PM			1 AM-3 AM			5 AM-7 AM		
Eye condition	Control lighting	Poorly lit*	Brightly lit	Control lighting**	Poorly lit**	Brightly lit**	Control lighting**	Poorly lit**	Brightly lit**	Control lighting	Poorly lit**	Brightly lit**
"Eyes open"	183.75	126.75	139.08	75.33	101.25	76.5	21.83	23.08	27.75	223.08	165.33	173.83
"Eyes closed"	176.25	233.25	220.92	404.67	378.75	403.5	458.17	456.92	452.25	256.92	314.67	306.17
Head position	Control lighting	Poorly lit**	Brightly lit*	Control lighting**	Poorly lit**	Brightly lit**	Control lighting**	Poorly lit**	Brightly lit**	Control lighting	Poorly lit**	Brightly lit**
Head "non-contact" with the floor	135.08	105.42	109.25	60.58	89.75	62.33	14.08	16.83	10.67	187.75	142.42	149.5
Head "contact" with the floor	224.92	254.58	250.75	419.42	390.25	417.67	465.92	463.17	469.33	292.25	337.58	330.5

* $P < 0.05$; ** $P < 0.01$, t test comparing positions under each lighting condition

Results

Eye position

During the experimental lighting period (4 PM-5:30 PM), the number of events of "eyes closed" was significantly greater than that of "eyes open" under exposure to poorly lit conditions ($t = -2.91$; $P < 0.05$; Table 2).

In 2 of the data recording sessions during lights-out (9 PM-11 PM and 1 AM-3 AM), the number of events spent with "eyes closed" was significantly greater than that with "eyes open" under all 3 experimental conditions ($P < 0.01$, respectively).

In the 5 AM-7 AM data recording session during lights-out, the number of events of "eyes closed" was significantly greater than that of "eyes open" under both poorly lit ($t = -5.49$; $P < 0.001$) and brightly lit ($t = -6.14$; $P < 0.001$) conditions.

Head position

During the experimental lighting period (4 PM-5:30 PM), the number of events of head "contact" was significantly greater than that of "noncontact" under either poorly lit ($t = -3.68$; $P < 0.01$) or brightly lit ($t = -3.48$; $P < 0.05$) conditions (Table 2).

In 2 data recording sessions during lights-out (9 PM-11 PM and 1 AM-3 AM), the number of events of head "contact" was significantly greater than that of "noncontact" under all the 3 experimental conditions ($P < 0.01$, respectively).

In the 5 AM-7 AM data recording session during lights-out, the number of events of head "contact" was significantly greater than that of "noncontact" after exposure to either poorly lit ($t = -6.24$; $P < 0.001$) or brightly lit ($t = -5.68$; $P < 0.001$) conditions.

Postures

During the experimental lighting period (4 PM-5:30 PM), there were no differences among the 3 lighting conditions in terms of the number of events spent in each posture. Dorsal recumbency was not observed. In the 3 data recording sessions during lights-out (9 PM-11 PM; 1 AM-3 AM; 5 AM-7 AM), the numbers of events spent in each posture were similar among the 3 lighting conditions (Table 3). The total number of events involving lateral recumbency from 5 AM to 7 AM after exposure to poorly lit conditions was significantly greater than that after exposure to control conditions (Tukey, $P < 0.05$).

Within each set of lighting conditions, the number of events spent in each posture during each recording session differed significantly (Table 3). From 4 PM to 5:30 PM, the number of events involving sternal recumbency was significantly greater than for sitting or standing under all the 3 experimental conditions (Tukey $P < 0.05$). From 9 PM to 11 PM, the number of events of lateral recumbency was significantly greater than that of standing, sitting, or in dorsal recumbency under all the 3 experimental conditions (Tukey $P < 0.05$).

From 1 AM to 3 AM, the number of events of lateral recumbency or curling up was significantly greater than that of sternal recumbency, dorsal recumbency, standing, or sitting after exposure to either control lighting (Tukey, $P < 0.05$) or brightly lit conditions (Tukey, $P < 0.05$). During this period, the number of events of lateral recumbency or curling up was also significantly greater than that of sternal recumbency, sitting, or standing (Tukey, $P < 0.05$), and the number of events of lateral recumbency was also greater than that of dorsal recumbency (Tukey, $P < 0.05$) after exposure to poorly lit conditions.

From 5 AM to 7 AM, the number of events of curling up was significantly greater than that of standing, sitting, or dorsal recumbency after exposure to either control lighting (Tukey, $P < 0.05$)

Table 3
Total number of events and standard deviations for each posture

Lighting condition	Observational period	Sternal recumbency	Lateral recumbency	Dorsal recumbency	Curling up	Sitting	Standing	*P* value
Control lighting (600 lux)	4 PM-5:30 PM	281.00 ± 47.78^{a}	116.50 ± 39.81^{a,b}	0^{b}	215.00 ± 53.05^{a,b}	54.83 ± 23.59^{b}	52.67 ± 28.33^{b}	0.0011
	9 PM-11 PM	141.67 ± 34.88^{a,b}	500.67 ± 117.11^{a}	0.67 ± 0.33^{b}	263.33 ± 146.32^{a,b}	8.20 ± 5.06^{b}	47.17 ± 33.64^{b}	0.0036
	1 AM-3 AM	31.17 ± 15.45^{b}	514.50 ± 118.13^{a}	1.25 ± 0.48^{b}	410.00 ± 123.63^{a}	2.40 ± 0.68^{b}	1.50 ± 0.56^{b}	<0.001
	5 AM-7 AM	193.67 ± 51.72^{a,b}	252.67 ± 79.52^{a,b}	0.75 ± 0.25^{b}	358.67 ± 95.89^{a}	69.67 ± 31.33^{b}	84.83 ± 51.95^{b}	<0.01
Poorly lit (50 lux)	4 PM-5:30 PM	344.83 ± 64.44^{a}	181.17 ± 44.73^{a,b}	0^{b}	131.67 ± 54.05^{a,b}	32.00 ± 14.75^{b}	30.33 ± 14.59^{b}	0.0001
	9 PM-11 PM	200.33 ± 67.54^{a,b}	409.50 ± 105.40^{a}	0^{b}	268.50 ± 117.75^{a,b}	28.20 ± 10.20^{b}	58.17 ± 49.64^{b}	0.0131
	1 AM-3 AM	26.67 ± 14.66^{c}	481.50 ± 113.25^{a}	65.75 ± 48.04^{b,c}	396.83 ± 136.93^{a,b}	7.60 ± 2.42^{c}	5.00 ± 1.83^{c}	<0.001
	5 AM-7 AM	202.83 ± 38.47^{a,b}	337.00 ± 44.90^{a}	0^{c}	285.33 ± 59.24^{a}	48.50 ± 16.95^{b,c}	86.33 ± 43.81^{b,c}	<0.001
Brightly lit (1600 lux)	4 PM-5:30 PM	276.0 ± 56.83^{a}	162.83 ± 48.68^{a,b}	0^{b}	226.17 ± 67.31^{a}	29.33 ± 11.41^{b}	25.67 ± 9.93^{b}	0.0013
	9 PM-11 PM	163.00 ± 60.41^{a,b}	459.67 ± 89.86^{a}	4.00 ± 4.00^{b}	279.17 ± 115.81^{a,b}	11.80 ± 6.44^{b}	46.33 ± 36.83^{b}	0.0011
	1 AM-3 AM	42.33 ± 24.73^{b}	471.50 ± 88.97^{a}	27.25 ± 27.25^{b}	421.83 ± 115.43^{a}	4.20 ± 1.46^{b}	2.50 ± 0.92^{b}	<0.001
	5 AM-7 AM	227.83 ± 26.18^{a,b}	257.17 ± 79.88^{a,b}	8.00 ± 8.00^{b}	346.50 ± 97.13^{a}	51.83 ± 23.76^{b}	71.33 ± 38.73^{b}	<0.01

Letters a, b and c indicate the significant difference within each lighting condition during each observational period (Tukey, $P < 0.05$).

or brightly lit conditions (Tukey, $P < 0.05$). The number of events of lateral recumbency or curling up was significantly greater than that of standing, sitting, or dorsal recumbency (Tukey, $P < 0.05$) after exposure to poorly lit conditions, but the number of events of sternal recumbency was greater than that of only dorsal recumbency (Tukey, $P < 0.05$) under these conditions.

Behaviors

For each behavioral category under control lighting conditions (600 lux), the numbers of events of yawning ($F[3,33] = 6.65$; $P < 0.01$) or stretching ($F[3,33] = 13.60$; $P < 0.0001$) differed significantly among some of the 4 data recording periods (Figure 1). The numbers of events of vocalization ($F[3,33] = 3.67$; $P < 0.05$), grooming ($F[3,33] = 4.84$; $P < 0.01$), or stretching ($F[3,33] = 6.92$; $P < 0.001$) differed significantly among some of the data recording periods under poorly lit conditions (50 lux; Figure 2). The numbers of events of vocalization ($F[3,33] = 3.47$; $P < 0.05$), yawning ($F[3,33] = 5.76$; $P < 0.01$), and grooming ($F[3,33] = 4.03$; $P < 0.05$) differed significantly among some of the data recording periods under brightly lit conditions (1600 lux; Figure 3).

There was no interaction between the 3 lighting conditions and the 4 data recording periods in terms of the number of events of each behavioral category.

Discussion

The poorly lit conditions (50 lux) that we used in this experiment seemed to promote sleep, likely because melatonin production is light dependent. Circadian regulation of pineal melatonin content in rodents seems to be 2 coupled oscillators; an evening or E (evening rise) oscillator associated with melatonin onset, and a morning or M (morning decline) oscillator associated with melatonin offset (e.g., Elliott and Tamarkin, 1994; Illnerová and Sumová, 1997). In a human study, Jelínková-Vondrasová et al (1999) suggest that the human circadian system might be influenced by the shifting of the sleep time under a dim light. It might be difficult to discuss the comparison of the relative tendency of melatonin onset and offset between our study and that of the other-species studies, because these studies have carried out a wide variety of lighting conditions which include different light intensities and durations. However, the lighting intensities used in our study led to a decrease in the dogs' arousal levels, and these results suggest that the dog's melatonin secretion was promoted under exposure to dim lighting conditions.

From 9 PM to 11 PM and 1 AM to 3 AM, all the conditions of luminous emittance had the same effects on eye or head position in the dogs. In contrast, during the data recording period from 5 AM to 7 AM, before rising, there were differences in effects between the experimental and control conditions. The number of events of "eyes closed" was greater than that of "eyes open," and the number of events of head "contact" with the floor was greater than that of "noncontact," after exposure to either poor or bright conditions, but not to control conditions. These results suggest that the dogs' arousal levels increased during 5 AM to 7 AM after exposure to control lighting. A change in luminous emittance before bedtime may influence not only the onset of sleep but also the activity in the hour or so before rising. If the lighting conditions in the evening are appropriate for comfortable rising, then before rising, the body prepares for a smooth shift to awakening from sleep. It was suggested that the response to a specific light stimulus in humans is evaluated thoroughly and systematically over the entire circadian

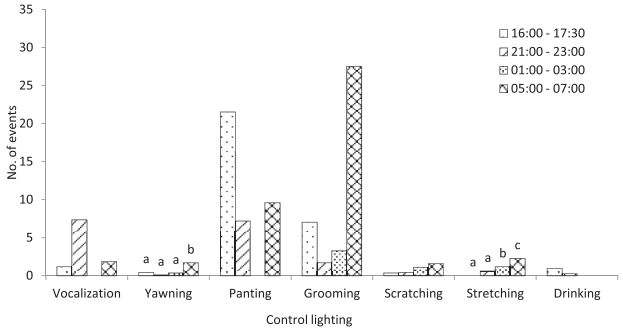

Figure 1. Total number of events spent in each behavior during and after exposure to control lighting conditions (different letters within each behavioral category indicate significant differences; Tukey, $P < 0.05$).

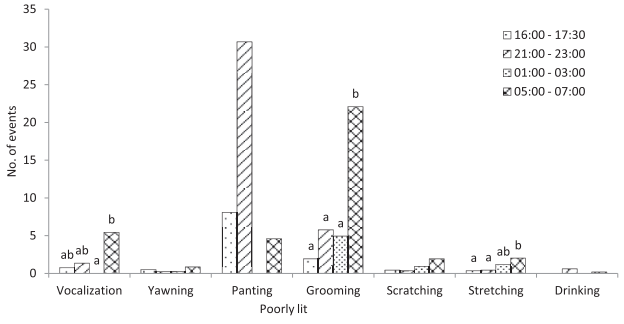

Figure 2. Total number of events spent in each behavior during and after exposure to poor lighting conditions (different letters within each behavioral category indicate significant differences; Tukey, $P < 0.05$).

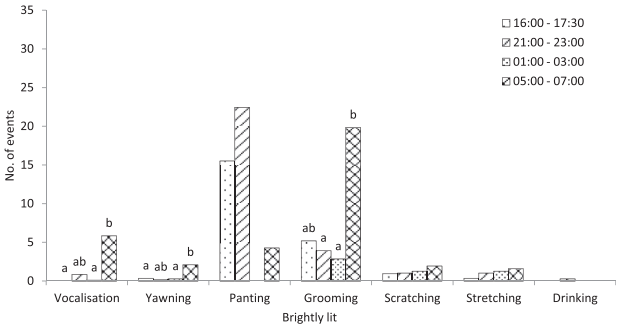

Figure 3. Total number of events spent in each behavior during and after exposure to bright lighting conditions (different letters within each behavioral category indicate significant differences; Tukey, $P < 0.05$).

cycle, and the exact shape and timing of the resulting phase response curve provides precise information concerning the overall relationship between phase-shift magnitude and the circadian phase of the stimulus over the entire circadian cycle (Khalsa et al., 2003). In our study, it was not clear whether differences in luminous emittance before sleep affected the morning shift into wakefulness in the dogs. The number of events involving vocalization or grooming from 5 AM to 7 AM was significantly greater than that from 1 AM to 3 AM under poorly lit or brightly lit conditions, but differences in luminous emittance did not directly affect the dogs' behaviors. Adams and Johnson (1994) reported that dogs are regularly awake (3 times per hour) during the night and will readily wake from sleep to bark in response to stimuli of significance to them. Our results indicated that differences in luminous emittance before bedtime affected the sleep-wakefulness cycle before the dogs rose in the morning. However, there are insufficient data on the relationship between luminous emittance and dog behavior; therefore, further studies are needed.

Unlike the behaviors, postures were influenced by changes in luminous emittance in each data recording period. From 4 PM to 5:30 PM, the number of events of curling up was greater than that of sitting or standing, but only during exposure to bright lighting. The number of events of sternal recumbency was greater than that of either sitting or standing under all the 3 lighting conditions. Sternal recumbency indicates a lower level of activity than does sitting or standing; this may be why lighting conditions of 50 or 1600 lux did not have a strong negative influence on the dog's activity as compared with exposure to 600 lux daily. Alternatively, the duration of the illumination was too short to have an effect. In dogs, the melatonin response to light is affected to the same degree as in humans (Shanahan et al., 1999). However, in that report, dim light was set at 10-15 lux and bright light was set at 9500 lux. The luminous emittance was thus lower (or higher) than in our study. For future experiments, we anticipate a wider range of lighting conditions and comparisons of responses among greater numbers of dogs.

During the data recording periods from 9 PM to 11 PM and 1 AM to 3 AM, the number of events of lateral recumbency was greater than that of standing, sitting, and sternal recumbency in response to all the 3 lighting conditions. These results suggest that the main rest posture in dogs was sternal recumbency when the lights were on and lateral recumbency when the lights were off. From 5 AM to 7 AM, the number of events of curling up was greater than that of standing, sitting, or sternal recumbency under either poorly lit (50 lux) or control (600 lux) conditions. In contrast, under brightly lit (1600 lux) conditions, both the number of events of lateral recumbency and the number of periods of curling up were greater than those for standing, sitting, or dorsal recumbency. The resting posture of dogs changed in the hour or so before rising, and this may have been affected by the luminous emittance the evening before. After exposure of the dogs to brightly lit conditions (1600 lux) before bedtime, the number of events of sternal recumbency was still greater than that of the other postures. Therefore, a luminous emittance of 1600 lux before bedtime may encourage stable sleep (or rest). However, posture during the "lights-out" period differed among individual dogs. More data are needed to determine the relationship between luminous emittance and sleep quality.

Conclusion

Changing luminous emittance before bedtime might influence sleep quality in dogs. Indicators such as eye or head position could be more useful than posture or behavior for assessing sleep quality.

Acknowledgments

The authors thank the 2 anonymous reviewers for their helpful comments and suggestions on the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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